

CHAPTER 2

FISH PASSAGE CONSIDERATIONS FOR ROAD CROSSING DESIGN

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2 FISH PASSAGE CONSIDERATIONS FOR ROAD CROSSING DESIGN

Roads crossings over permanent or seasonal waterways are generally classified as one of three types:

- bridges,
- culverts, or
- low water crossings (also referred to as fords).

For the purposes of this manual, it is assumed that low water crossings are outside the scope of a typical Caltrans projects, and the discussion of road crossings will be limited to bridges and culverts. Bridges are defined by the National Bridge Inspection Standards (NBIS) as those structures which have at least 6 meters of length along the roadway centerline. A culvert is defined by the *Highway Design Manual* (HDM) as “a closed conduit which allows water to pass under a highway”, and it is noted that a single culvert site may actually have multiple barrels to accommodate the conveyance needs.

Traditional road crossing design procedures, such as the culvert design procedures described in *HDS No. 5*, typically focus on conveyance of the design flood, as a means to establish practical limits on the goal of perpetuating natural drainage. While these traditional procedures include consideration of backwater affects, excessive velocity, erosion, and traffic safety issues, they generally do not provide specific consideration of the needs for fish passage. Road crossing sites requiring fish passage must use design procedures that assess the conveyance characteristics from a “fish eye” view.

This chapter discusses several important concepts in fish passage design from three approaches. First, as a means to emphasize that the design procedures have a basis in the fish requirements, there is a discussion of key biological factors known to affect fish mobility and migration, as well as mention of broader environmental conditions that, while they may not affect fish mobility, have direct relation to fish survival. Secondly, there is discussion of hydraulics and hydrology issues that are of particular relevance to fish passage design, touching upon the interrelationship between geomorphic processes and ecosystem function. Finally, there is discussion of several engineering design, construction and maintenance topics that are commonly applied in any road passage design, but which may have special or unusual circumstances when applied to fish passage road crossings. In the subsequent chapters of this manual, specific design procedures are presented to allow more thorough evaluation of these engineering considerations.

2.1 Factors Affecting Fish Passage Success at Road Crossings

The most common problems typically associated with fish passage at road crossing structures are:

- water velocities that are greater than the swimming capabilities of the fish (Figure 2-1a.);
- perched outlet conditions that result in a vertical drop that exceeds the jumping and leaping capabilities of the fish (Figure 2-1b);
- shallow water depths or sheet flow conditions that do not provide adequate swimming depth for the fish (Figure 2-1c); and
- debris accumulations that cause physical blockage or create excessive turbulence that surpasses the swimming capabilities of the fish (Figure 2-1d).

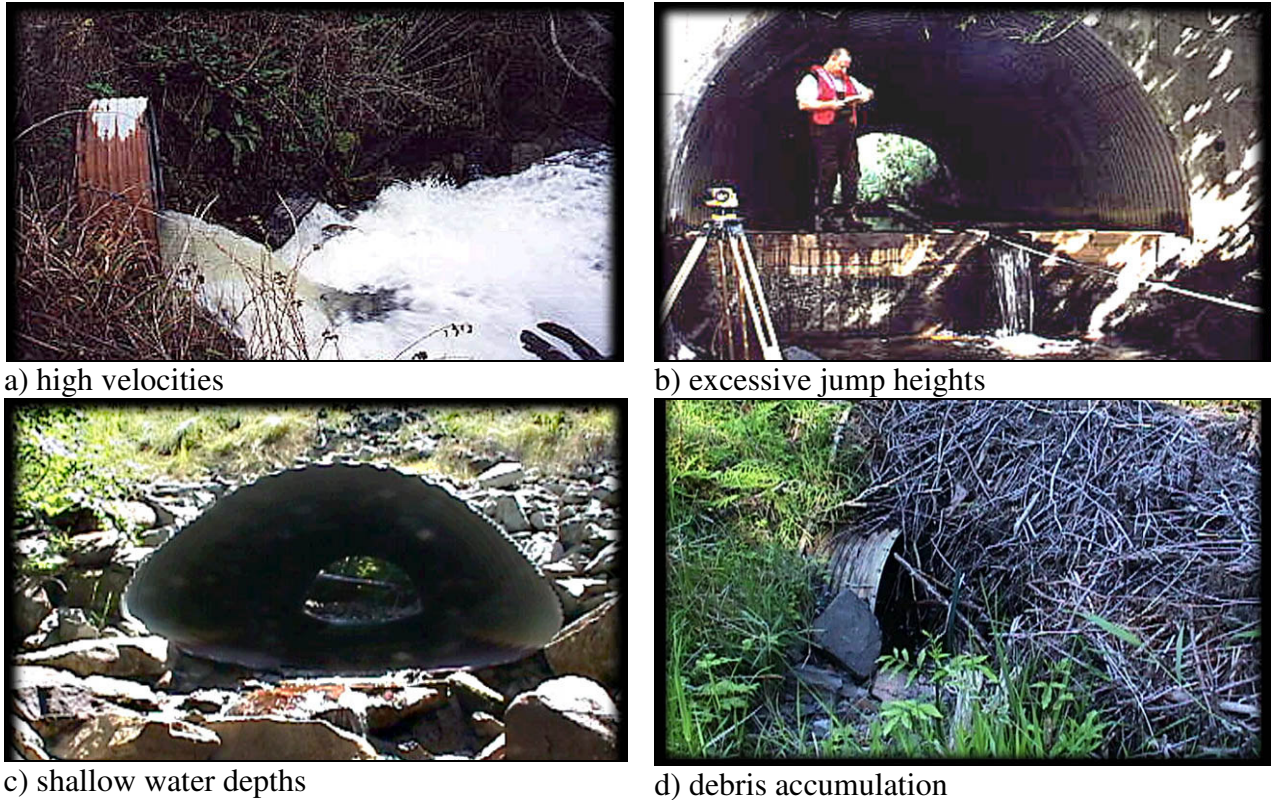


Figure 2-1. Common barriers to fish passage at road crossings. (Photos courtesy of FishXing 1999)

The ability to overcome these fish passage problems is dependent on a number of factors which are discussed in the following subsections.

2.1.1 Swimming and Leaping Capabilities of Fish

Aquatic systems exhibit tremendous diversity in their hydraulic conditions, ranging from the relative calm of lakes and reservoirs to the higher energy conditions of mountain streams. The types of fish that inhabit these diverse conditions have swimming capabilities that reflect their environmental surroundings. The swimming capabilities of various fish species exhibit differences both in the speed they can attain, as well as their endurance in maintaining these speeds over time. Discussions of fish swimming capabilities commonly address three different modes of swimming considering an average condition:

- Sustained speed: a speed that can be maintained indefinitely by the fish, reflecting the swimming mode commonly used for movement. Some researchers use the term cruising speed to described sustained swimming.
- Prolonged speed: a speed that can be maintained for a limited duration, such as might occur with passage through difficult areas. This is the mode of swimming typically used for design or analysis of road crossings. Prolonged swimming can be maintained from 15 seconds to 200 minutes, depending on the species. Some researchers use the term sustained speed in place of prolonged speed, creating unfortunate confusion with the slower classification of sustained/cruising speed.
- Burst speed or darting speed: a speed attained for a short burst of effort, such as in feeding or escaping predators, but not capable of prolonged effort.

Threshold levels for the sustained, prolonged and burst speeds have been identified for a number of fish species. In addition to significant variation between species, there is also variation between different age classes of the same species (Figure 2-2). Environmental factors such as location in watershed relative to other obstacles, increased water temperature, or poor water quality can influence the ability of a fish to maintain the typical speeds common for that species and age class.

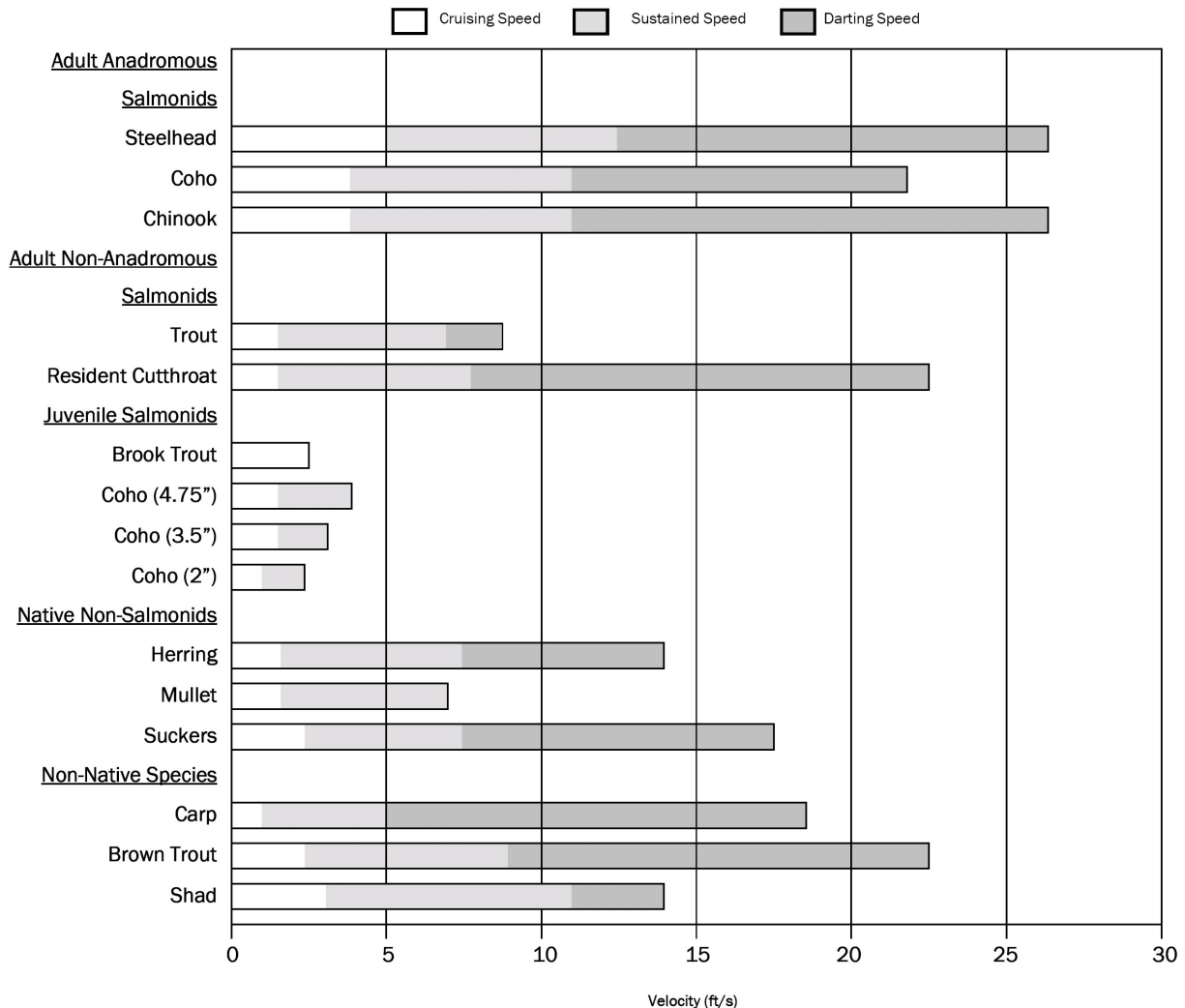


Figure 2-2. Swimming capabilities of various species and age classes of fish. The list organizes the data into five classifications of fish commonly referenced in California fish passage guidelines. (Adapted from Bell 1991)

The relevance of these swimming capability differences to fish passage design is to recognize that the design criteria for a specific road crossing site will depend on the fish species and age classes for which it is desired to provide passage. Identification of the fish species and age class of interest (frequently called the target species) should be obtained from Environmental staff prior to beginning the design for a fish passage road crossing. If the design process is initiated using assumed target species, there is risk the design efforts will have to be reinitiated if the target species is redefined.

2.1.1.1 Velocity Barriers

Road crossings create a geographic division in the habitat of a fish species. The ability of a fish species to utilize the adjacent habitat areas may be lost on a temporary or permanent basis if the velocities at the road crossing exceed the prolonged swimming capabilities of the target species. The phenomenon in which velocity conditions prohibit access is called a velocity barrier.

Velocity barriers may result in direct loss or underutilization of available habitat, which is likely to result in reduced numbers of the fish population.

Road crossing design processes presented in this manual insure that velocity conditions remain below the prolonged swimming capabilities of the target species, for those flows typical of fish movement. (During flood conditions, fish are likely to be seeking refuge in calm water and not choosing to move upstream.) Alternatively, the road crossing design may provide resting areas spaced frequently enough to allow the fish to dart from one location to the next. The methods of analysis for insuring there are no velocity barriers vary depending on the type of road crossing selected for design.

2.1.1.2 Jump Height Barriers

Similar to the diversity in swimming capabilities, there is also great diversity in the leaping capabilities of various fish species. Of the fish species common to California, the leaping capabilities of adult Chinook, coho, and steelhead are especially notable. These species all exhibit life histories that involve both an ocean phase and a fresh water phase, and they may undergo upstream migrations of hundreds of miles from the ocean to reach their freshwater spawning grounds. These characteristics place them in a classification known as anadromous salmonids. Salmonids which do not exhibit the ocean-going trait include resident trout and resident cutthroat. The adults of these non-anadromous salmonids do not have the same leaping capabilities as the anadromous salmonids. Similarly, the jumping capabilities of juvenile salmonids and non-salmonids (such as most species that inhabit lakes and reservoirs) are not nearly as strong as those of adult salmon.

Culverts installed in the past without consideration to fish passage were most frequently placed to match the natural streambed elevation. However, in some cases (such as sites requiring very high fills), culverts were installed considerably above the stream elevation, resulting in a perched condition at the culvert outlet. It is a testimony to the persistence of nature that some adult anadromous salmonids are able to leap in to and successfully pass these perched culverts. There is a much lower likelihood of juveniles or any other classification of fish being able to pass these perched culverts.

New and replacement culverts installed where fish passage is a requirement are generally required to place the culvert so that there is no change in elevation between the thalweg of the stream and the bed of the culvert. In limited cases, such as when an existing culvert is being retrofit to enhance fish passage, a drop in the water surface of 6 to 12 inches may be allowed, depending on the target species. These inherent measures to ensure there are no jump height barriers vary according to the road crossing design option that is selected.

2.1.1.3 Shallow Water Depths

Fish movement requires sufficient water depth for the following reasons:

- Fish that are only partially submerged do not achieve the same level of thrust as occurs from body and tail movements of fully submerged fish.

- If the gills of the fish are not fully submerged, they will experience reduced oxygen uptake, which may affect swimming ability and endurance.
- Shallow water depths may increase the level of physical contact with the stream bed, increasing the risk of physical injury or predation.

Factors that can cause shallow water depths at road crossings include placing the culvert at a steep slope, and the use of wide, flat-bottomed culverts and aprons. The fish passage road crossing design processes presented in this manual insure that water depth conditions are within threshold levels for the target species, or that they are similar to natural stream conditions, depending on the design option that is selected.

2.1.2 Debris

As runoff accumulates from a watershed, it naturally carries certain floatable material with it. In watersheds with significant vegetation, natural growth cycles as well as cutting or clearing operations may contribute to debris and drift in the runoff. As this debris approaches and passes through a highway drainage facility, it has potential of becoming hung up or jammed. Because urbanization continues to increase across the State, urban debris, such as tires and shopping carts, is becoming more widespread and blocking low-flow routes. Significant accumulations of debris can reduce hydraulic efficiency, cause local scour, and cause physical damage to the facility and adjacent property and features. With even low to moderate accumulations of debris at a road crossing, the velocity and turbulence affects may be significant enough to create a fish passage barrier.

Debris accumulation is a common characteristic of any drainage feature, natural or manmade, in which there is a constriction in the flow path. Though it is not possible to eliminate the risk of debris accumulation entirely, there are road crossing design strategies that can reduce those risks. Very generally, the larger the conveyance opening, the less risk there is of having debris problems. Since fish passage road crossings tend to be larger than culverts designed through traditional cross drainage methods, there is some reduction of risk inherent with any of the fish passage road crossing design methods. Additional measures are presented in Chapter 3 that may help the designer understand the potential for debris accumulation and damage, and assist with the design of protective devices and access features to facilitate debris maintenance operations.

2.1.3 Bed Load

The bed load in a stream is defined as sediment that moves by rolling, sliding, or skipping along the bed. Effectively, sediment load means the same thing. The bed load or the sediment load in an undisturbed stream system is, over the long term, usually in a state of equilibrium, in which eroded material is replaced by deposited material. Changes in hydrology as occur in nature over seasons or over the duration of a flood event may create erosion (or channel degradation) on the rising and peak flows of a cycle, while deposition (or channel aggradation) occurs with the falling flows.

Road crossings that present a significant constriction in channel geometry may produce erosive velocities that cause channel degradation below a culvert. Constrictions may also produce backwater conditions above the culvert that result in deposition and channel aggradation. Both of these conditions tend to steepen the channel slope in the vicinity of the culvert, with the potential result of creating a velocity barrier in the channel approaching or exiting the culvert.

Since design methods for fish passage road crossings generally aim to maintain velocities in the range of the swimming capabilities of fishes, these same design methods inherently reduce the problems of bed load erosion or deposition that sometimes occur with traditional culvert design methods. Depending on the design method selected, there are varying degrees of attention given to ensuring that bed load movement continues unhindered through the road crossing. In special cases, analyses may be conducted on the stability of bed material under flood conditions, to minimize the risk of significant channel degradation and aggradation over the life of the project.

2.1.4 Ambient Lighting Conditions

The response of fish to lighting conditions varies with species and age. Some fish are known to be attracted to light, other fish are indifferent to it, and others try to avoid it. Adult salmon tend to avoid strobe lights. Juvenile salmon use light to orientate themselves and are attracted to light, but they also appear to establish a threshold to that attraction, perhaps as an innate protection against predation.

Adult salmon approaching the minimally-sized Hells Gate Fishway on the Fraser River in British Columbia exhibited reduced delay entering the fishway following installation of lights. At the same time, Washington State has numerous culverts more than 1,000 feet long under the cities of Olympia, Tacoma, West Seattle, and Bellingham. Monitoring reports indicate these culverts have good fish passage, even though there are no lights in these culverts (P. Klavas, WDFW, pers. comm., October 2004).

In some instances, fisheries agencies may require that ambient or artificial supplemental lighting be provided in proposed culverts over 150 feet in length. Environmental staff should identify at the onset of a fish passage design whether fisheries agency representatives will require application of this criterion for culvert crossings at specific project sites.

2.1.5 Uncertainty of Fish Passage Streamflows

Traditional culvert design methods focus on hydraulic conditions resulting from the design flood, frequently defined as the 25-, 50- or 100-year event. Fish passage design methods, on the other hand, are concerned with the hydraulics resulting from the typical year-to-year conditions in which the target population inhabits the stream. Depending on the type of fish passage road crossing selected for design, it may be necessary to determine the flow rate for certain frequently-occurring flows, such as the 2-year flow (Q_2). Additionally, since it may be necessary to check that the design provides adequate depth for fish passage (again being dependent on the design type), it may be necessary to estimate the lowest expected discharge occurring when the target species is present.

Stream gage data, if available, provide the most accurate way to calculate fish passage flow rates. However, few gaged streams exist in comparison to the total number of streams in California, and the probability of having gage data for the specific project site is low. It is more likely that the fish passage streamflows will be estimated using a hydrologic method such as those described in Section 3.2. However, because of the uncertainty of these methods, and because of importance of velocity on assessing the fish passage conditions, it is recommended that the estimates be used conservatively. Engineering judgement should be applied to fish passage flow estimates in steeper watersheds and urbanized or urbanizing watersheds, where land use and basin hydrology may change during the life of the project, thereby affecting the maximum and minimum flows.

2.2 Types of Fish Passage Road Crossings

There are several types of structures that can be involved with fish passage at road crossings. Those discussed in this manual include the broad classifications of bridges, culverts, grade control structures, and fishways. Bridges and culverts are the two classifications that provide the actual function of cross drainage for the road crossing. Grade control structures and fishways are two classifications of fish passage facilities that, when applied to road crossings, generally function to insure fish passage is maintained in the stream channel on either side of the road crossing. Each of these broad classifications have several design subtypes that differ according to factors such as structural capability or design objective. The following section discusses each of the four classifications of fish passage road crossing structures and identifies the major design subtypes that are most relevant to Caltrans projects. Key differences of each subtype with respect to fish passage function are discussed.

2.2.1 Bridges

From a fish passage perspective, bridges are the preferred method of providing a fish passage road crossing, for the simple reason they cause the least change in the stream channel. This general openness of a bridge crossing allows the greatest degree of ecological connectivity between the watershed basin upstream and downstream of the road crossing. The connectivity is important to not only to fish populations in the stream, but also to other aquatic organisms and wildlife that utilize the stream corridor. Bridges also allow the most natural form of transport for large debris, sediment, and other stream elements that are important in stream forming processes and in the health and maintenance of the entire stream ecosystem.

Bridge crossings (without aprons) may be the only form of road crossing that can accommodate fish passage requirements when the stream grade is over 8%. If the stream grade is in the range of 5% to 8% and flowing over bedrock, an embedded culvert is likely to be the practical alternative.

Bridge design for fish passage road crossings should require little more hydraulic and hydrologic analyses than is typically required for a typical bridge design. At complex sites where there is limited data regarding stream hydrology, selection of a bridge crossing design may eliminate the need and uncertainty of evaluating fish passage over a range of flow rates.



Figure 2-3. Bridge crossing

The relatively large flow area of bridges, as compared to culverts, generally produces a greatly improved condition of reduced risk of plugging from debris and sediment.

The main drawback to bridges, in comparison to culverts, is the significant difference in construction cost. As a general guideline, however, the cost of a bridge may become comparable to that of a culvert once the culvert dimensions begin to require multi-plate designs in excess of 10 feet in diameter or 15 feet in span (Robison et al. 1999).

When conducting a benefit-cost analysis that includes consideration of the long-term costs associated with maintenance, however, it is worth noting that bridges may offer an increased benefit over culvert alternatives when applied to a fish passage projects, as compared to the typical analysis involving non-fish passage culverts. Debris and sediment removal is essential for all road crossings, whether they are required to provide fish passage or not, from the standpoint of preventing highway overtopping and protecting the structural integrity of the road crossing.

2.2.2 Culverts

As knowledge regarding fish passage at culverts has progressed in recent years, it has become common to classify culverts by the design method used for their development. This manual focuses on four classifications of culvert design that, very generally, provide differing degrees of culvert openness as a means to promote ecological connectivity. The four classifications, presented in decreasing order of culvert openness, are:

- stream simulation design
- active channel design
- hydraulic design
- existing culvert retrofit.

The following subsections provide a brief introduction to each style of culvert and the common application where the style is used.

2.2.2.1 Stream Simulation Culvert

Stream simulation is a culvert design method intended to create and maintain natural stream processes in a culvert. It is based on the premise that the simulated channel inside a culvert presents no more of a challenge to movement of water, organisms, sediment and debris than the adjacent natural channel. As such, the stream simulation design method is expected to provide passage to all species and age classes of fish, as well as to all other aquatic organisms in the stream.

In the stream simulation design approach, basic culvert characteristics of slope, cross-sectional size, and culvert bed elevation are derived from characteristics of nearby stream reaches that are similar to the road crossing location (Figure 2-4). This method therefore can provide fish passage at sites having stream slopes up to 6%, and in some cases, even higher.

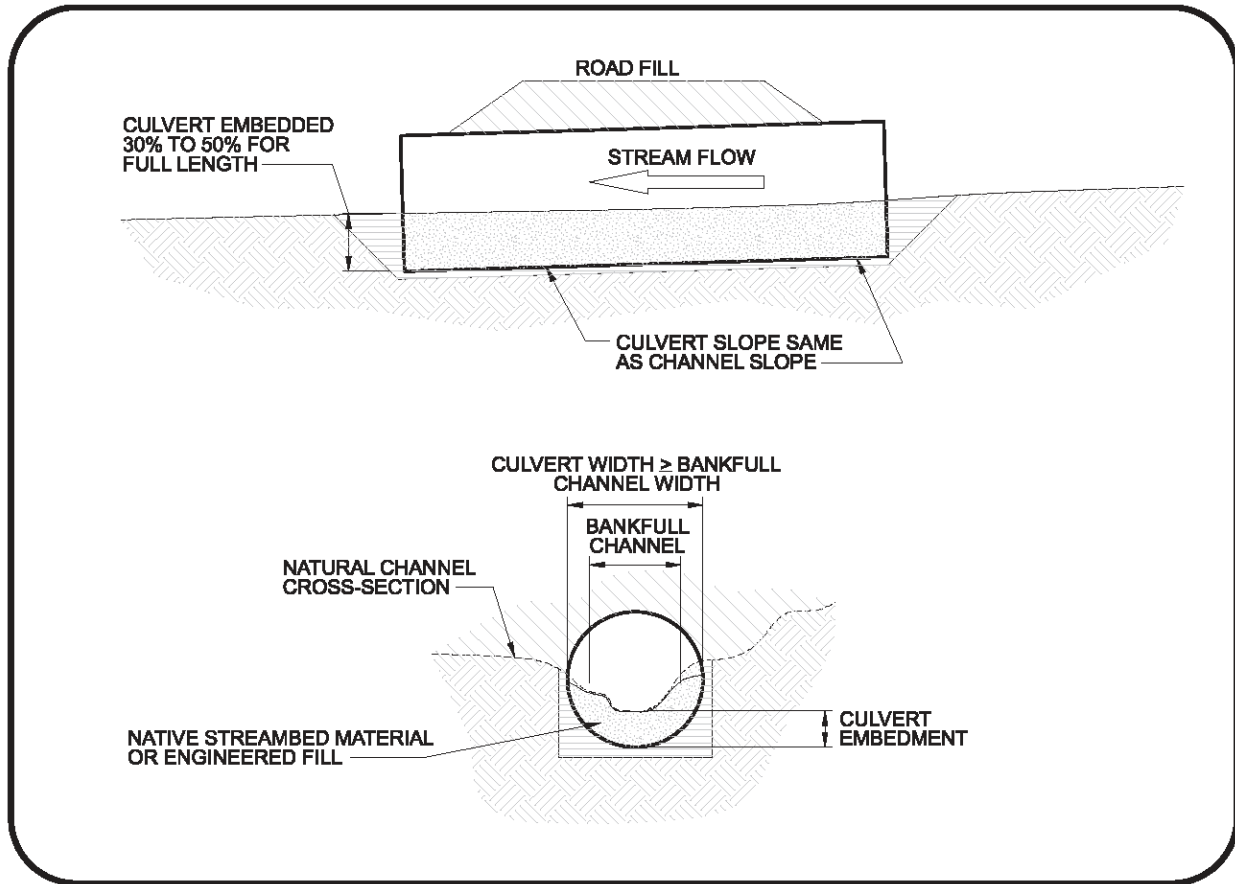


Figure 2-4. Basic sizing and embedment concepts of stream simulation culverts.

The general premise that hydraulic conditions in the culvert will mimic those in the natural stream reduces the amount of hydrologic and hydraulic analysis necessary for design development. Sites that have limited hydrologic data may choose to select a streambed simulation design approach as a means to reduce the risk associated with uncertain conditions for fish passage flows.

Streambed simulation culverts are sized to be at least as wide as the natural stream channel, and there is high probability they will be larger than culverts designed by the active channel or hydraulic design methods for the same site. As such, the streambed simulation method is likely to yield designs having higher capital cost than the other two culvert design methods. At the same time, the long-term maintenance costs of a streambed simulation design should be lower than the two culvert alternatives, for the same reasons of reduced maintenance as described for the bridge option. The lowest ratio of comparative construction cost between streambed simulation and the alternative culvert design methods is most likely to occur at road crossings located in narrow stream valleys.

2.2.2.2 Active Channel Culvert

An active channel design employs a culvert placed at a level grade, sized sufficiently large enough to encourage the natural movement of bedload and the formation of a stable bed inside the culvert. The active channel design method originally was developed with the intent of

providing a simplified stream simulation design for private landowners with short crossings under driveways and similar sites. For those limited projects satisfying specific criteria regarding channel slope and culvert length, the active channel design method can greatly reduce the engineering effort necessary to develop a culvert design approved by State and Federal fisheries agencies. The tradeoff for the reduced engineering effort is that it provides a road crossing culvert that is commonly larger than would be required under more rigorous hydraulic design approaches.

In the active channel design approach, basic culvert characteristics cross-sectional size and culvert bed elevation are derived from characteristics of adjacent stream reaches that are similar to the road crossing location (Figure 2-5). Key differences from the stream simulation method are 1) the culvert is placed at a flat slope, and 2) the culvert is sized in relation to the active channel width of the stream, instead of the bankfull width. (Section 3.1 provides definitions and greater detail regarding data collection for channel characteristics.)

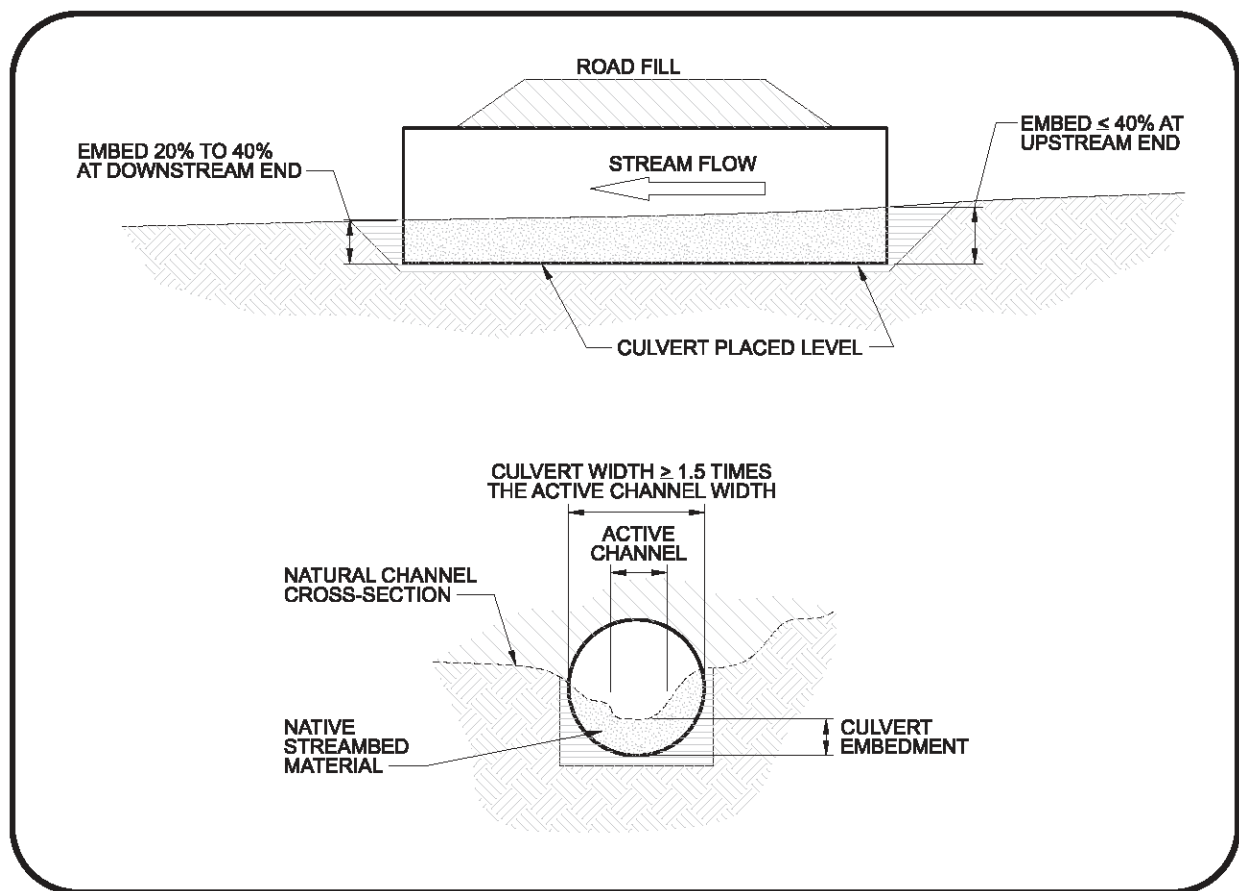


Figure 2-5. Basic sizing and embedment concepts of active channel culverts.

The active channel method can be used only at sites having stream slopes of 3% or less, and in cases where the culvert length will be less than 100 feet. Because it is necessary to embed the culvert, this method should not be used where there is bedrock near the stream surface.

2.2.2.3 Hydraulic Design Culvert

The hydraulic design option for new fish passage culverts is the option most similar to the conventional method of designing culverts for highway cross drainage. However, there is a significant difference between these two methods in the design parameter that plays the key role in determining the culvert configuration. In the conventional approach to hydraulic culvert design, the design parameter that most frequently determines the culvert size is the allowable headwater elevation. In contrast, the fish passage approach to hydraulic culvert design will most frequently size the culvert using a design parameter specifying the maximum average velocity within the culvert barrel.

Adaptation of the conventional culvert hydraulic design method to fish passage applications has led to the development of “fish passage criteria” that must be satisfied by the design. In California, there are five distinct classifications of fish species and life stage groupings that have unique fish passage criteria. Use of the hydraulic design option for culvert design requires that the fish species and life stage classification, commonly referred to as the “target population”, be identified so that the appropriate fish passage criteria can be applied. The general premise of the design is to size the culvert so that velocities do not exceed the prolonged swimming capabilities of the target species. Fish that are weaker swimmers than the target population may be unable to pass the crossing.

Because of the requirement that the culvert velocity stay within certain limits, the hydraulic design method generally requires much more analytical effort than the active channel or stream simulation methods. A hydrologic analysis is performed to define the upper and lower flow conditions for fish passage, as well as to determine the peak flood. Hydraulic analyses are performed to evaluate flow characteristics below the culvert outlet, within the culvert barrel, and above the culvert inlet. Multiple iterations are often required to find a successful solution.

Successful application of hydraulic design culverts is generally limited to sites having channel slopes of 3% or less. Project sites located in areas classified as anadromous salmonid spawning areas are not allowed to construct new or replacement culverts using hydraulic design methods. Hydraulic design culverts are likely to be smallest structure that can satisfy fish passage criteria. Because they involve the smallest structural size, the construction costs of hydraulic design culverts are likely to be less than active channel or stream simulation culverts. However, design costs and maintenance costs for hydraulic design culverts are likely to be greater, both on a per site basis and expressed as a percentage of the construction cost.

2.2.2.4 Existing Culvert Retrofit

Many existing culverts were developed without consideration of fish passage. Fish passage evaluations conducted by Caltrans and other entities



Figure 2-6. Baffles under low-flows

throughout California have identified individual culverts that inhibit fish migration. Some of these culverts are included in prioritized lists of fish passage improvement projects that give consideration to factors such as the amount of spawning habitat that would become available if passage were restored.

The most effective solution for improving fish passage through an existing culvert is to replace it with a new structure designed using relevant fish passage design criteria. However, there are cases in which culvert replacement is difficult to justify, such as when the existing culvert is relatively new and has a significant remaining design life, or when there are plans to replace the culvert 5 or 10 years in the future as part of other planned roadway improvements. In such cases, a decision may be made to improve fish passage through the existing culvert to the extent possible, using culvert retrofit methods included in this manual.

Culvert retrofit projects use the same design methods as hydraulic design culverts, with improvements addressing the needs of specific fish classifications. Retrofit measures typically involve the addition of roughness elements within the barrel of the existing culvert, either through the use of baffles or roughened channels. Since these projects retain the same barrel size as the original design, the risk of debris accumulation and sediment retention upstream of the culvert rarely improves from the original installation, and indeed culvert retrofits have high potential to make debris and maintenance issues even worse. Considerable engineering design effort is required to insure the improvements achieve fish passage improvements without excessive impact to transport of flood waters, debris and bed load.

2.2.3 Grade Control

Basic sizing and embedment concepts of stream simulation culverts. Grade control structures are used in fish passage culvert projects to enhance fish passage conditions in the stream channel upstream and downstream of the culvert, as well as in the culvert itself. The three most common uses of grade control structures involve 1) developing an outlet pool below the culvert that increases water depth and backs water into the culvert barrel, 2) creating a series of small pools or resting areas in steep sections of channel above or below the culvert, and 3) stabilizing the channel streambed near the culvert.



Figure 2-7. Concrete Weirs

Two common types of grade control structures used in stream channels are rock or concrete weirs and roughened channels. Weir types of grade control create a step-pool arrangement in the stream, and they are usually limited to channel slopes of 5% or less. Roughened channels use large rocks to create small pools behind each rock which fish can dart between; roughened channels routinely have slopes as high as 6%, and there are examples of successful installations having slopes 8% and above.

2.2.4 Fishways

Fishways are defined as a structure that allows fish passage around a natural or man-made barrier, such as at dams or natural waterfalls. As applied to road crossing design, fishways might be used in rare cases where the elevation differential necessary to achieve fish passage is so great that normal in-stream grade control measures will not be feasible. A common example is a culvert that was originally designed strictly for hydraulic performance that has its outlet located high above the stream channel. The drop at the outlet may be so steep



Figure 2-8. Concrete fishway

that it would require an unacceptably long horizontal distance to accomplish the grade change using the usual maximum slopes of grade control weirs or roughened channels. In such cases, a fishway may provide a solution. A fundamental difference between fishways and grade control measures is that fishways are designed to pass only a portion of the stream flow (usually around 10%), while grade control measures accommodate the entire stream flow. This operational difference adds another level of complexity to the design, and passage performance is dependent on fish being able to distinguish the fishway entrance discharge from the impassable streamflow discharge. Fishways require significant design effort, capital cost, and commitment to facility maintenance, and they are generally considered a “last resort” after all other potential solutions have been explored.

2.3 Design, Construction and Maintenance Considerations

This section discusses several engineering design, construction and maintenance topics that are commonly applied in any road passage design, but which may have special or unusual circumstances when applied to fish passage road crossings. Topics include:

- Limited right of way
- Durability
- Construction schedules
- Constructability
- Best management practices
- Maintenance risks
- Maintenance access
- Monitoring requirements
- Mitigation requirements

2.3.1 Limited Right of Way

In developing the design of a culvert it is always preferable to stay within the existing Right of Way. However for those circumstances where a new installation cannot be maintained within the existing Right of Way it is incumbent upon the designer to identify the need for additional right of way and construction easements as soon as possible due to the time required to secure new right of way.

Culvert retrofitting projects often require additional rights of way to allow the development of hydraulic conditions conducive to fish passage at the downstream and upstream ends of the culvert. Conditions such as scour and channel headcutting can create an impassable condition at the downstream end of a culvert due to excessive vertical differential in the stream channel.

Conditions such as aggradation can lead to impassable conditions in a channel upstream of a culvert inlet as the acceleration of the flow entering the culvert can cause a benching of aggraded sediments in the channel upstream of the inlet.

In both of these circumstances grade control structures such as weirs can be utilized to maintain a passable hydraulic condition. As these types of structures typically allow for an overall average slope of 5% to be maintained, it is not uncommon to have a need to install several of these structures to step down or up to tie into existing grades. The required spacing of the structures and need for clearances to allow construction often times requires the work for a considerable distance up or downstream of the channel and can create the need for more channel length than is contained within the existing right of way. Channel side slopes can also become problematic as grades within the channel are modified. Often times headcutting and scour holes create side slopes of questionable stability, the grading back of these slopes to a more stable configuration often control the width of the additional right of way needed for a retrofit project. When determining the needs for additional right of way, future access for maintenance purposes should also be considered.

An alternative to weirs is the use of a roughened channel. These channels are created with large riprap and use rock “weirs” to provide hydraulic paths for fish passage with the allowable gradients being dictated by hydraulic criterion. These are still somewhat experimental in nature but typically can be designed to function at steeper slopes than can be achieved with series of weirs leading to less overall area being required for an installation.

2.3.2 Durability

Any Caltrans fish passage road crossing structure must be designed to the same drainage design standards and objectives as described in HDM Chapter 800. These standards usually require a 25 to 50 year service life for any designed installations. In addition to the cross drainage conveyance structure, these standards apply to any fish passage features constructed in the stream channel above and below the crossing, such as grade control structures and fishways. Grade control structures should be constructed of extremely durable materials such as rock and reinforced concrete. Additionally, materials specified for use in a project must be appropriate to the environment in which they are being installed.

2.3.3 Construction Schedules

Construction schedules for fish passage facilities are often confined to certain seasonal periods and time durations when construction is allowed to take place in a stream. These periods, commonly called the construction window, are typically set by regulatory authority on a case by case basis and depend on the types of species present in any given reach of stream. Often times these windows are rigidly maintained and must be adhered to even if it means abandoning a project in a non-finished state.

This information should be obtained early on the design process for consideration of time constraints possibly ruling out certain types of construction. This information should also be clearly spelled out in the specifications and if it is determined that there is a risk of a contractor

being unable to complete the work within the specified Construction Window, an abandonment plan should be included in the project.

There will also be instances where a construction window will be granted on a One Time Basis due to the need to minimize the impact of an installation. In this circumstances it is suggested considerable attention be paid to monitoring the contractor's activities and even consider an alternative award process to ensure a highly qualified contractor is doing the work.

2.3.4 Constructability and Estimating

Constructability is always a consideration relative to the cost of a project. In considering the constructability of a project thought must be given to access of equipment and personnel relative to work that must take place in the riparian corridor and that which must occur within any culvert structure. Given that most of the work in any given stream will be subject to time constraints allowed by a permitted Construction Window, thought must be given to the time required to build a given design and the ability to work around any other constraints at a given site.

When estimating the cost of a project consideration must be given to such factors as:

- “Construction Windows” for when the work can take place
- Special restrictions as to what equipment can be used in the actual channel
- Size and production capability of smaller equipment required for work in confined areas such as within culverts
- The amount of labor required for certain construction such as the hand labor in the construction of bedrock channels
- Onsite monitoring, direction and modification required for placement of rock weirs or other boulder features.
- Specialty equipment required for boulder placement and adjustment
- Dewatering and diversion requirements

Much of this can be conveyed to the construction contractor through project plans and specifications where final configurations are clearly delineated, requirements for the final installation clearly defined and any restrictions or constraints required by permits are spelled out.

Certain special functions, such as that associated with the adjustment of boulders forming rock weirs are more typically covered by the specification of the contractor having a certain machine of given capability with operator available for a certain duration.

2.3.5 Permit Conditions

Construction activities for fish passage projects may require permits that place conditions or constraints on work activities. Often times these permit conditions refer to Best Management Practices, which may be established by local, state, or federal entities for various activities. These should be clearly spelled out for the contractor as they can impact cost and the scheduling of certain construction activities. Failure to identify these requirements can lead to fines and stoppage of work and the subsequent activities to establish responsibility can be a long process.

2.3.6 Maintenance Risk

Road crossings located where there is significant movement of large woody debris or accumulation of bed materials should account for the natural transport of these materials past the

crossing or accept the need to conduct periodic maintenance to remove accumulations. Natural deposition zones are often created where there is a significant decrease in the channel gradient, such as occurs at the junction of a tributary entering the floodplain of a larger river. Culverts installed in these locations tend to fill with bed materials, and periodic sediment removal may be necessary. Bridges or streambed simulation culverts are the most appropriate design strategy for road crossing locations having high loadings a debris or sediment, as these styles are large enough to allow more natural transport of channel materials.

2.3.7 Maintenance Access

Design should provide means to access the road crossing structure for routine maintenance and monitoring. Locations where access is poor might give greater consideration to selecting a bridge or streambed simulation culvert road crossing design, in order to reduce the maintenance requirements.

2.3.8 Monitoring Requirements

- Structural Integrity – monitoring routinely conducted by Caltrans for facility condition.
- Passage Performance – additional monitoring that may be required by fisheries agencies as condition of design approval. The designer will need to coordinate with the Environmental unit to ascertain that permit conditions and the facility design are coordinated and reflect anticipated performance conditions.

2.3.9 Mitigation Requirements

Depending on the circumstances of project siting, project designs may result in unavoidable impacts to wetlands or other special habitats that support plants or wildlife of special significance. In these cases, it may be necessary to provide mitigation to compensate for the impacts. Mitigation measures might include additional plantings along a stream, improvements to water quality control systems (grass lined swales, small sedimentation basins) or efforts to minimize sedimentation from other sources. These types of improvements may also assist in obtaining additional right-of-way where required, as a landowner will indirectly benefit from these activities.

The designer should work closely with the District Environment Unit to identify protected or sensitive habitat as soon as possible after project startup. Efforts should be made to avoid these areas, or to minimize the direct impact when it is not possible to avoid them altogether.

2.4 Preliminary Selection of Fish Passage Road Crossing Type

With an understanding of the basic issues associated with fish swimming performance, road crossing performance, and the various considerations of design, construction and maintenance, it is usually possible to identify the one or two fish passage road crossing types that are the best candidates for design development. A preliminary screening balances measures that provide the greatest advantage to fish passage, with other measures that may provide significant economic advantage. An underlying premise is the potential requirement of obtaining approval from the State and Federal fisheries agencies, and hence it is necessary to be aware of conditions where certain types a crossings are not allowed. For new and replacement culverts, the key factors contributing to selection of appropriate road crossing type are described below and summarized in Table 2-1.

- **Target Species** – Identification of the target species for which passage is required can be a key factor in deciding type of road crossing should be used. When passage is required for juvenile fish, it is often difficult to achieve compliance with the velocity criteria of the hydraulic design method, except in cases where the channel slope is essentially flat.
- **Length** – Culverts having lengths greater than 100 feet are not appropriate for the active channel design method, since the requirements for vertical embedment generally result in an uneconomical amount of culvert volume being used for non-conveyance purposes.
- **Spawning Areas** – Anadromous salmonid spawning areas are a limited resource protected by the California Department of Fish and Game (CDFG) and the National Oceanic and Atmospheric Administration Fisheries Division (NOAA Fisheries). These agencies specify that proposed road crossings in anadromous salmonid spawning areas must use bridges, the stream simulation design method, or the active channel design method. Areas containing spawning habitat are not allowed to use the hydraulic design method.
- **Slope** – Sites having slopes up to 3% may be able to develop a successful fish passage structure using any of the design methods, especially if the outlet can be backwatered or if the culvert is designed to be embedded. Slopes greater than 3% will probably require use of the stream simulation culvert method or a bridge. Slopes greater than 6% will probably require a bridge.
- **Economics** – The presence of surficial bedrock generally requires use of a bridge or open bottom stream simulation culvert. Hydraulic design culverts in general are significantly lower in cost than stream simulation culverts, which in turn are usually less costly than bridges. The trend is most apparent with smaller streams, less than 10 to 15 feet in width. The cost differential between hydraulic and stream simulation designs is usually less significant where the stream is located in a narrow valley.

Table 2-1. Key parameters for preliminary selection of road crossing type.

Site Parameter	Bridge	Stream Simulation Culvert	Active Channel Culvert	Hydraulic Design Culvert
Anadromous salmonid spawning habitat				Not allowed
Target fish species	All	All	All	Must identify; juveniles difficult
Maximum slope		6%	3%	3%
Maximum length			100 feet	
Minimum width		Greater than bankfull width; 6 ft min.	Greater than 1.5 x active channel width	3 feet